All Shook Up: The LADEE Spacecraft Vibration Mishap

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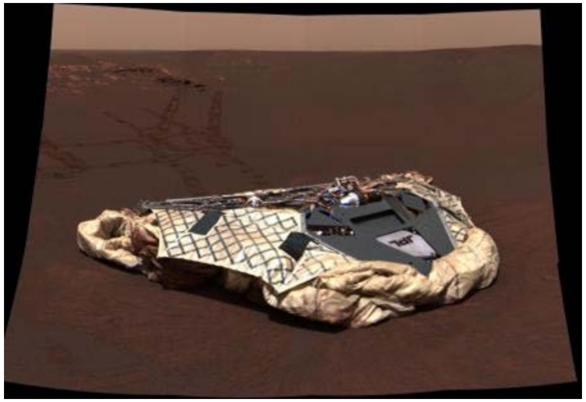
The Needful Risk of Test Failure

- Numerous NASA projects have used dynamic tests to ensure that payloads and launch systems function reliably despite extremes in environmental stressors. Examples of test failures that improved vehicle reliability and odds of mission success include the Spirit and Opportunity landing tests; test failures on simulated Martian terrain showed how to protect both landers when they bounced onto Mars itself.
- Such effort represents “needful risk,” when lessons pay off with the engineering of tough, capable vehicles.
- In the LADEE sine burst test, demonstrations of risk imposed by one choice of test type among options and risk imposed by unlearned yet available lessons from the past are palpable—a reversal of the conventional test failure—where the failure was in the testing itself. Going forward, improved capture of and access to test failure analyses at the right time in their lifecycles, can pay dividends beyond those gained through project failure analysis.



Opportunity’s Empty Landing Nest. Source: NASA.

LADEE undergoing laboratory testing. Source: NASA.

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Background

- Vibration testing was underway for the Lunar Atmosphere and Dust Environment Explorer (LADEE) Engineering Test Unit (ETU), a project between Ames Research Center (ARC) and Goddard Space Flight Center (GSFC). ARC possessed strength testing facilities, but not facilities for sine-burst vibration testing—a GSFC-developed method of applying a quasi-static load, using a vibration shaker and shock testing software. An off-site contractor was chosen based on cost, experience, and proximity to ARC.

What Happened

- May 3, 2012, LADEE was mounted on the vibration shaker sliptable, which was successfully demonstrated weeks prior with a non-representative test article.
- The procedure included tests to identify LADEE’s fundamental frequencies, a burst test in three increasing increments, and finally, another sweep to compare post-burst integrity.
- The default plan called for one third and two thirds test levels to check for linearity in the test data before performing full level tests at 2 G’s.
- During test setup, the NASA Test Director (TD) and the contractor Test Engineer (TE) discussed the start level for the calibration phase of the test. The control system software default startup would deliver several pulses to LADEE. The TD wanted to minimize the loading cycles on LADEE and the TE deleted the lower level pulses. This resulted in a high start level of 2 G’s because the shaker required the low level pulses to properly calibrate. The sliptable moved violently, emitted a loud bang, and automatically shut down.
- Damage was isolated to composite cruciform panels within the propulsion structure. Two vertically-oriented shipping accelerometers (10 G- and 15 G-thresholds) on the cruciform panels had tripped.

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Proximate Cause

- Preexisting frictional force from misaligned and seized bearings likely caused the sliptable system to compute (from the calibration pulse) abnormally high voltage to achieve the first test level.
- Overriding the control system start pulse value likely worsened the issue. Sine burst tests are short duration and open loop, with no correctional feedback capacity from control accelerometers.

Underlying Issues

Missed Opportunities

- Contractor experience was limited: TE did not fully understand the sliptable control system. The NASA investigation found that the LADEE team did not execute aspects of the LADEE System Safety and Mission Assurance Implementation Plan and the Risk Management Plan. Further, personnel test responsibilities weren't understood. Contractor surveillance was not accomplished and testing risks were not tracked.
- The ARC Internal Audit Program lacked independence and adequate staffing to thoroughly review the project.

Sine-Burst Hazards and Unforeseen Costs

- The Lessons Learned Information System (LLIS) was not queried for sine burst test cases. Investigators determined that less risky test methods were available with cost and schedule tradeoff.
- Sine burst testing is used extensively within NASA, but not in industry. Many testing houses do not have experience or understanding of the risks and mitigation strategies. Development teams typically lack knowledge related to vibration test equipment, compounding the problem.

Aftermath

- The investigators recommended a revision of NASA Standard 5001A, Section 4.1.2.1, Test Methods, to include the risks of sine burst testing and a link to the Lessons Learned Information System entry for the High Energy Spectroscopic Imager Test (HESSI) Mishap (http://www.nasa.gov/offices/oce/ llis/0903.html), noting that similar sine burst testing mishaps have occurred throughout the Agency.
- The investigators recommended that ARC implement a System Safety and Mission Assurance (SS&MA) Technical Authority process that ensures issues pertaining to the Project and Center SS&MA requirements are reviewed, and resolved at an appropriate level of SS&MA Authority.

Relevance to NASA

- Project review needs to occur at a level where the risks of specific testing are understood.
- Although this mishap occurred at a contractor facility, it could have been avoided if NASA personnel were better trained and educated in the intricacies of sine-burst testing and general test discipline.
- Despite knowledge-transfer means at NASA and across the industry, awareness of this testing risk needs to improve.

Minotaur V expendable launch system. Its maiden flight carried the LADEE spacecraft payload. Source: NASA.